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Research Article
Size Reduction of Groundnut Shell by Ball Mill and Estimation of Breakage Parameters Using Population Balance Model

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Abstract
Background and Objective: Many physical mechanisms involved in industrial milling for size reduction, Comminution helps to reduce higher average particle size to smaller one. The aim of the work is to investigate the breakage rate function for the size reduction of groundnut shell using ball mill. **Materials and Method:** At first stage, the experiment was carried out with ground nut shell whose average size is about 3.2 mm weighing about 100 g is fed and operated at different time (10, 15 and 20 min), ball loading (number of balls 4, 7 and 10) and RPM of the ball mill (60, 70 and 80 rpm). At each grinding time, the product size distribution was determined by sieve analysis. The above experimental procedure was repeated at different process variables. After sieving, the average particle size was calculated. The optimized value was found meanwhile breakage distribution function parameter and grinding rate calculated using population balance model method. **Results:** The best correlation for the parameter with process variables was obtained by multiple linear regression analysis. The correlation describes the experimental data fits with the simulated data for ground nut shell. The calculated values of the breakage rate obtained through the developed correlations have been compared with the respective experimental values with root mean square error and correlation coefficient. It is also found that the calculated values agree well with the experimental values. **Conclusion:** It is concluded that population balance model can be used to find breakage size distribution.

Key words: Groundnut shell, ball mill, population balance model, multiple regression analysis, breakage parameters

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Early days people use biomass like wood chips, sawdust, rice husk for heating and burning. But biomass like straw, palm fiber are not suitable for direct use and they often have large size that makes storage or transportation cost much higher. Besides, the direct use of wood chips and certain biomasses sometimes cannot combust fully. For convenient transportation and storage and for easy combustion, biomasses are made in to pellet and briquette. For making both pellet and briquette, biomass raw materials should be pulverized first. The high pressure of pellet mill machine can press the powdery biomass tightly and make them not easy to break. Biomass pellets are usually utilized in home pellet stove, central heating boiler, industrial boiler, or in power plants to replace coal. They can also be used as horse bedding and cat litter[1-3].

Ball mills are one of the most commonly used milling equipment approximately 20% of the energy generated by the mill is utilized for actual grinding of the material. The crushing efficiency is due to various factors such mill load, rotation speed, type of milling as well as the size of the balls. Many researchers investigated various materials size reduction using different types of mechanical crushers. Sakthivel and Pitchumani[4] investigated effect of operating parameters such as ball loading , solid mass fraction , pH of the suspension and grinding time on particle size (silica) distribution for the production of nano mineral particles in a stirred ball mill using response surface modeling. The particle size was decreased with the increase in ball loading, pH and grinding time, but not solid mass fraction. Eswaraiah[5] studied the size reduction characteristics of rice husk in a batch ball mill. The breakage rate function parameters with process variables such as feed size, ball charge were calculated and modeled using population balance model. Prichici *et al*.[6] studied and reported the distribution of energy in the grinding charge of ball mill as a function of the number of impact between the balls and the grinding material inside the ball mill with different diameters and different values of the rotational speed. Gil *et al*.[7] calculated Bond work indexes values for three Turkish coals. The response surface methodology is used for modeling the variables of model were Bond work index, grinding time and ball diameter of mill. Celep *et al*.[8] studied optimization of some parameters of stirred mill on ultra-fine grinding of refractory Au/Ag ores. Grinding tests were carried out in a laboratory scale pin-type vertical stirred mill. Ball diameter, grinding time, ball charge ratio and stirrer revolution was presented as empirical model equations. Kumar and Subba Rao[9] investigated grinding Dolomite ore using ball mill with the parameters like time of grinding, ball size, feed quantity, feed size by applying response surface modeling. Specific energy consumption also decreases with feed quantity at all ball sizes. Gao and Forssberg[10] realized that the first order breakage hypothesis is not valid in fine grinding and that the process mechanism differs substantially from that for ball mills. Dolomite of a known feed size distribution was grounded in a stirred ball mill. Size energy model is used for predicting the product size distribution. This model has two parameters reduction ratio and pseudo size of the product. The product size distribution below 10 µm from a stirred ball mill was stimulated by this model. A model has been developed for ball mill based on plug flow assumption. The kinetics and the breakage mechanism of different types of feed by ultrafine dry grinding was studied by Babu and Prasad[11], the results of this experiment shows the change in the specific rate of breakage of material with respect to different size fractions and the energy requirement for different size fractions of feed. In comparison with rotary drum ball mill this consumes more energy for dry (feed) grinding. The present investigation biomass size reduction of ground nut using the ball mill has been attempted and using a population balance model a correlation has been developed for the breakage distribution function.

MATERIALS AND METHODS

Study area: This study was carried out at Alagappa College of Technology, Anna University, Chennai, Tamil Nadu. Ground nut shell is collected from nearby village in Villupuram, near Chennai. The ground nut shell is dried in the open sun and stored in the plastic bag for the experiment. The work is conducted from July, 2017 to April, 2018 with the facility available in the Department of Chemical Engineering.

Ball mill experiment: Initially the ground nut shell is crushed and then subjected to the ball mill for further size reduction. The ball mill consists of a hollow cylindrical body of 26.8 cm diameter made up of stainless steel is filled with steel balls of 76.2 mm diameter. The ball mill was rotated at 60 rpm (critical speed = 82.8 rpm). Average feed size of 3.2 mm of groundnut shell weighing about 100 g was fed into the ball mill. The ball mill is operated at different time (10, 15 and 20 min), ball loading (number of balls 4, 7 and 10) and RPM of the ball mill (60, 70 and 80 rpm). At each grinding time, the product size distribution was determined by sieve analysis. The above experimental procedure was repeated at different process variables. After sieving, the average particle size was calculated.

Modeling on ball mill: The batch grinding equation is known as population balance model McCabe *et al.*[12]. The material mass balance for entering and leaving of a given size fraction is given. If the input and output from a given screen are at equal rates, the fraction retained on that screen remains constant. Usually this is not the case and the mass fraction retained on screen n changes according to the Eq. 1:

$$\frac{d_x}{dt} = -S_n X_n + \sum_{u=1}^{n-1} S_u X_u \Delta B_{n,u} \quad (1)$$

where, S_u and $\Delta B_{n,u}$ are constant. $B_{n,u}$ is breakage distribution function, S_u is grinding rate function, X_u is the mass fraction retained on upper size, t is grinding time. Let n be the number of particular screen in the stack. For convenient purpose we can number it from top down, beginning with the coarsest screen. For any given value of n, let upper screen coarser than screen n, designated by the subscript u. The breakage function depend on the reduction ratio D_n/D_u according to the equation:

$$B_{n,u} = \left(\frac{D_n}{D_u}\right)^{\beta} \quad (2)$$

$$\Delta B_{n,u} = B_{n-1,u} - B_{n,u} \quad (3)$$

where in equation 2, β is the breakage distribution function parameter and it is dependent on the material. The value may be constant or vary with the value of B.

Breakage rate (specific rate of breakage) S_i is defined as the fraction of material of size D_i broken per given time:

$$S_i = S_1 \left(\frac{D_i}{D_1}\right)^{\alpha} \quad (4)$$

where, α is breakage rate parameter, S_1 is grinding rate of first sieve. Breakage rate function parameter α is process dependent and related to process variables such as ball charge, feed size, rpm, ball size.

Equation 1 is solved by Euler's numerical approximation in which changes in all fractions during the successive short interval are calculated by approximation:

$$\frac{d_{x_n}}{dt} = \frac{\Delta x}{\Delta t} \quad (5)$$

$$\Delta x_{n+1} = x_{n,t+1} - x_{n,t} \quad (6)$$

The successive value x of can be calculated as:

$$x_{n,t+1} = x_{n,t} - s_n \Delta t\, x_{n,t} + \Delta t \sum_{u=1}^{n-1} x_{u,t} s_u \Delta B_{n,u} \quad (7)$$

RESULTS

The following results have been obtained from the size reduction of ground nut shell using ball mill experiment. The cumulative mass fraction for the different experimental parameters such as grinding time, ball loading and RPM of the ball is given in the Table 1. It is observed that the particle size decreases with increase in grinding time and with increase in RPM. It indicates that the distribution

Table 1: Biomass size reduction with different process variables

	Cumulative (%)					
	Time: 10 min, 70 rpm		Time: 20 min, 70 rpm		Time: 30 min, 70 rpm	
D_P (mm)	4 balls	10 balls	4 balls	10 balls	4 balls	10 balls
0.425	57.14	69.07	42.50	58.5	67.23	71.29
0.3	67.51	76.61	55.80	71.6	74.90	78.05
0.25	76.19	83.18	67.23	79.2	80.90	84.81
0.21	81.16	87.50	76.72	84.1	84.60	86.59
0.18	87.51	91.16	89.10	90.5	87.67	89.20
0.15	94.92	96.55	96.40	97.2	92.08	93.23

D_P: Diameter of the particle, rpm: Revolution per minute of the ball mill becomes narrow with increase in grinding time. A particle size 0.3 mm is taken with grinding time 10 min, 70 rpm and with 4 and 10 balls. The particle size reduction in 4 balls is lower when compared to 10 balls in different grinding time. From Table 1, it is observed that, when ball loading increases with grinding time, there is increase in size reduction. It is found that smaller particle size, X_d, is obtained at grinding time 30 min, 70 rpm. From Table 1 it shows particle size decreases with increasing RPM and ball loading, this may due to that there is an increase in ball-ball collisions instead of ball particle collision. The least particle size obtained at ball loading 10 and 70 rpm. Above 70 rpm there is no size reduction because the ball-ball collisions will be higher than normal. When grinding of a material increase with increase in rpm, the mean energy consumption for grinding increases. The energy consumption decreases with increasing rpm. To calculate breakage rate parameter and distribution function, the total mass fraction will be smaller in 50/60 mesh resulting from the breakage of 40/50 mesh. The fraction of broken material retained on 60th mesh screen is calculated as 1-0.797 = 0.203. Therefore, $\Delta B_{n,\,u}$ varies with composition of the material. If β is constant then the particle size distribution of the crushed material is same for all size of initial material. Breakage distribution function parameter (β) was calculated with the help of breakage distribution function shown in Table 2. The breakage function can be calculated for particular screens (n) it clearly shows that the particle is grinded completely. The root mean square error versus breakage distribution function parameter is presented in the Table 3. The root mean square error (RMSE) versus breakage distribution function parameter shows that breakage values decreases and then increases. From this result the breakage distribution function was found to be 1.2 with mean RMS error of 1.7% (0.017). The experimental value for breakage rate parameter for different breakage rate function is given in the Table 4. A computer program was developed to find the values of breakage rate function parameter (α) and breakage distribution parameter (β) for groundnut shell, by varying β value from 0-3 (with 0.1 increment) and for each value of β, α was varied from 0-3 (with 0.01 increment). Breakage rate function for different experimental parameters such grinding time, ball loading and ball mill RPM is given in the Table 5. The minimum error and its corresponding α for a particular β were found. With these results optimized correlation was found.

A correlation was made for breakage rate function parameter along with process variables such as ball charge, RPM, grinding time a set of experiments were conducted. Correlation data for dependent and independent value are given in Table 5. The best correlation was found to be:

$$\alpha = 0.005(T)+0.002(R)+0.003(B)+0.04 \quad (8)$$

Model validation is performed by correlating the experimental results with the predicted values obtained using multiple regression analysis. Figure 1 shows the comparison of predicted and experimental breakage rate function parameter. Predicted breakage rate function parameter is close to the actual experimental results.

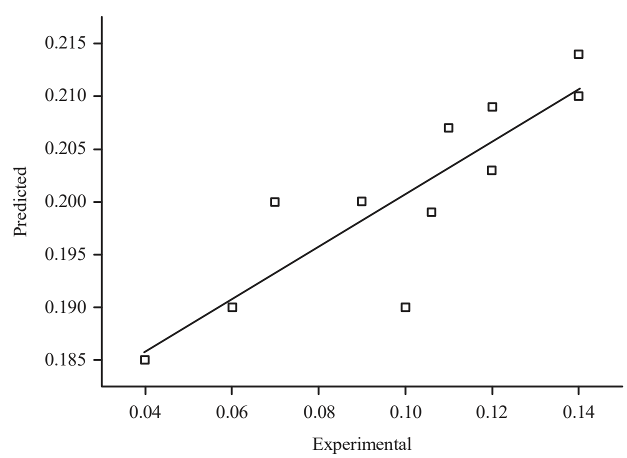

Fig. 1: Comparison of experimental and predicted breakage rate parameter

Table 2: Breakage functions for different β values

β	u	1	2	3	4	5	6
0.1	1	1	0.797	0.652	0.51	0.406	0.327
		0	0.203	0.145	0.138	0.108	0.079
	2	0	1.0	0.818	0.645	0.509	0.411
		0	0.0	0.182	0.173	0.136	0.098
	3	0	0.0	1.0	0.788	0.622	0.5
		0	0.0	0.0	0.211	0.166	0.12
	4	0	0.0	0.0	1.0	0.788	0.64
		0	0.0	0.0	0.0	0.211	0.148
	5	0	0.0	0.0	0.0	1.0	0.327
		0	0.0	0.0	0.0	0.0	0.67
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0
0.3	1	1	0.949	0.906	0.857	0.812	0.77
		0	0.051	0.043	0.049	0.045	0.042
	2	0	1.0	0.954	0.903	0.855	0.814
		0	0.0	0.046	0.051	0.048	0.041
	3	0	0.0	1.0	0.946	0.896	0.85
		0	0.0	0.0	0.054	0.05	0.046
	4	0	0.0	0.0	1.0	0.946	0.901
		0	0.0	0.0	0.0	0.054	0.045
	5	0	0.0	0.0	0.0	1.0	0.951
		0	0.0	0.0	0.0	0.0	0.049
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0
0.5	1	1	0.916	0.848	0.774	0.707	0.651
		0	0.084	0.068	0.074	0.067	0.056
	2	0	1.0	0.925	0.845	0.771	0.71
		0	0.0	0.075	0.08	0.074	0.061
	3	0	0.0	1.0	0.912	0.833	0.76
		0	0.0	0.0	0.088	0.079	0.073
	4	0	0.0	0.0	1.0	0.912	0.84
		0	0.0	0.0	0.0	0.088	0.072
	5	0	0.0	0.0	0.0	1.0	0.92
		0	0.0	0.0	0.0	0.0	0.08
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0
0.7	1	1	0.885	0.79	0.775	0.615	0.548
		0	0.115	0.095	0.015	0.16	0.067
	2	0	1.0	0.89	0.79	0.69	0.619
		0	0.0	0.11	0.1	0.1	0.071
	3	0	0.0	1.0	0.88	0.774	0.69
		0	0.0	0.0	0.12	0.106	0.084
	4	0	0.0	0.0	1.0	0.88	0.784
		0	0.0	0.0	0.0	0.12	0.096
	5	0	0.0	0.0	0.0	1.0	0.89
		0	0.0	0.0	0.0	0.0	0.11
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0
1.0	1	1	0.84	0.72	0.6	0.5	0.42
		0	0.16	0.12	0.12	0.1	0.08
	2	0	1.0	0.857	0.714	0.595	0.505
		0	0.0	0.143	0.143	0.119	0.09
	3	0	0.0	1.0	0.83	0.694	0.588
		0	0.0	0.0	0.17	0.136	0.106
	4	0	0.0	0.0	1.0	0.833	0.706
		0	0.0	0.0	0.0	0.167	0.127
	5	0	0.0	0.0	0.0	1.0	0.848
		0	0.0	0.0	0.0	0.0	0.152

Table 2: Continued

β	u	1	2	3	4	5	6
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0
1.2	1	1	0.811	0.67	0.54	0.435	0.357
		0	0.189	0.141	0.13	0.105	0.078
	2	0	1.0	0.83	0.66	0.536	0.44
		0	0.0	0.17	0.17	0.124	0.096
	3	0	0.0	1.0	0.799	0.645	0.528
		0	0.0	0.0	0.201	0.154	0.117
	4	0	0.0	0.0	1.0	0.803	0.658
		0	0.0	0.0	0.0	0.197	0.145
	5	0	0.0	0.0	0.0	1.0	0.82
		0	0.0	0.0	0.0	0.0	0.18
	6	0	0.0	0.0	0.0	0.0	1.0
		0	0.0	0.0	0.0	0.0	0.0

β: Breakage distribution function parameter which is dependent on the material, u: Screen order

Table 3: Root mean square error vs. breakage distribution function parameter

Breakage distribution function parameter (β)	Root mean square error (RMSE)
0.5	0.01
0.6	0.022
0.7	0.02
0.8	0.024
1.0	0.023
1.1	0.052
1.2	0.017
1.3	0.062
1.4	0.068
1.5	0.19

Table 4: Experimental value for breakage rate parameter for different breakage rate function

	S_i						
D_1/D_2	α = 0.05	α = 0.06	α = 0.07	α = 0.08	α = 0.11	α = 0.12	α = 0.15
0.84	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.857	0.009923	0.009908	0.009893	0.009877	0.009832	0.009817	0.009771
0.833	0.009833	0.0098	0.009767	0.009734	0.009636	0.009604	0.009507
0.833	0.009743	0.009693	0.009643	0.009593	0.009444	0.009395	0.00925
0.848	0.009663	0.009598	0.009532	0.009467	0.009275	0.009211	0.009024

S_i: Grinding rate of a material, α: Breakage rate parameter, D_1/D_2: Size reduction ratio

Table 5: Correlation data for dependent and independent value

Breakage rate parameter	Grinding time	RPM	Ball loading
0.05	10	60	7
0.06	30	60	7
0.07	10	80	7
0.08	30	80	7
0.1	10	70	4
0.11	30	70	4
0.12	10	70	10
0.13	30	70	10
0.14	20	60	4
0.15	20	80	4
0.16	20	60	10
0.17	20	80	10
0.18	20	70	7
0.19	20	70	7
0.2	20	70	7

DISCUSSION

Breakage distribution function parameter and breakage rate parameter has been estimated using population balance model. Result from this study shows that particle size decreased with increase in grinding time, RPM, ball loading, this agrees well with the report of Sakthivel and Pitchumani[4]. Breakage distribution function parameter and grinding rate calculated using most popular method population balance model have been associated to get the optimized value[5,7,12]. There is a change in the specific rate of breakage of material with respect to different size fraction it goes agree with another study of Babu and Prasad[11]. When comparing with other researcher's work this study shows that the correlation and validation of a breakage distribution function parameter and breakage rate parameter using population balance model matches well with high correlation coefficients (R^2>0.9)[7].

CONCLUSION

The size reduction characteristics of the groundnut shell were studied using the population balance model. From the simulation the best-fit breakage distribution function for ground nut shell has been obtained using a computer program. Using breakage distribution function parameter and breakage rate function at different process variables were calculated. The grinding time, ball loading and RPM has a significant effect on the performance of ball mill. The correlation was verified by conducting additional experiments with groundnut shell. It was found that the correlation could able to predict the product size distributions with reasonable accuracy.

SIGNIFICANCE STATEMENT

This study discovered that the possible and optimized grinding value of a material using multiple regression analysis and predict the size distribution. This study will help the researchers to use population balance method to find appropriate grinding value of material.

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